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Kinematics and Kinetic Measurement of Normal Human Locomotion through Gait Analysis - A Pilot study

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ABSTRACT

Gait analysis is an oldest technique for the study of motion of a body parts. Recently, there has been great improvement in the field of movement analysis. There is a continuous improvement of new methods, combined with traditional ones. In this paper the kinematics and kinetic data of five normal and healthy subjects were collected and analyzed in detail. The purpose of this study is to analyze the kinematics of ankle, hip, and knee joints in different plane to understand the salient features of the trajectories. It was found that knee motion was limited to the sagittal plane. Ankle motion was found relatively small yet they are essential for shock absorption and progression of the body's center of mass.

INTRODUCTION

The human gait is a pattern of locomotion and can be described by kinetic or kinematic characteristics [1]. Therefore a complete study of normal human locomotion requires an understanding of both the kinematics and the kinetic involved. This is equally true in appreciating the problems of pathological gait. The gait cycle is described in terms of the significant events which occur during both the stance and swing phases. The basic principle of normal human locomotion is the subject of investigation many scientists and researchers [2-7]. Measurement of kinematics and kinetic has proven to be one of the greatest challenges in gait analysis [8-10]. Until now, many authors only measure sagittal motion (doris/plantarflexion), with a few routinely reporting frontal plane (inversion/eversion) kinematics. [11]

This study aims to presents kinematics and kinetic measurement data of human lower limb gait analysis. The experimental observations provide not only input but also validation for any mathematical models of leg mechanism. The knee and ankle joint trajectory in both coordinates calculated with the experimental setup. In order to find out the various positions of joints to calculate the trajectory ,ground reaction forces of the limb and body action of normal subject analytical and experimental both techniques used.

METHOD

The experiment was conducted at the Motion Analysis Laboratory, Department of Physiotherapy and Rehabilitation, Research & Referral, Army Hospital, New Delhi Cantt. The methodology of the experiment can be divided into three main steps; the experimental setup, the experiment and the results analysis. The experimental setup involved preparation of the laboratory and the proper setting up of the software used for gait analysis. The experiment was initiated by taking the anthropometric parameters of the subject.

Five healthy male Subjects aged 22-34, participated in the investigation. This group was anthropometrically similar (body weight: 60.4-67.6 kg, mean 64 kg; height: 1.48m-1.68m , mean 1.58 m). During the preparation phase, certain anatomical patient measurements (such as knee width and ankle width) were taken and markers were attached. The subjects were tested in the gait laboratory. The kinematic and kinetic data were sampled at 50 Hz. Each subject was required to wear short trousers and walk barefooted.

The setup was consisting of force platform with camera, EMG amplifier (Figure 1). The walking patterns of the subjects were captured and analyzed by a three-dimensional Vicon motion- analysis system. The six cameras had a frame rate of 60 fps and used infrared (IR) light-emitting diode strobes. Lightweight reflective markers were attached to the skin over the following bony landmarks: Sacrum (S2), Anterior superior iliac spines (ASIS), Lateral thigh, Knee-joint axes, Lateral shank, lateral malleoli, Second foot ray. A workstation was used for data transfer, analysis, and storage. Ground reaction forces during the stance phase were recorded by two strain-gauged force platforms, dimensions (508 x 460 mm)

Figure 1 **Experimental apparatus of motion capture system**

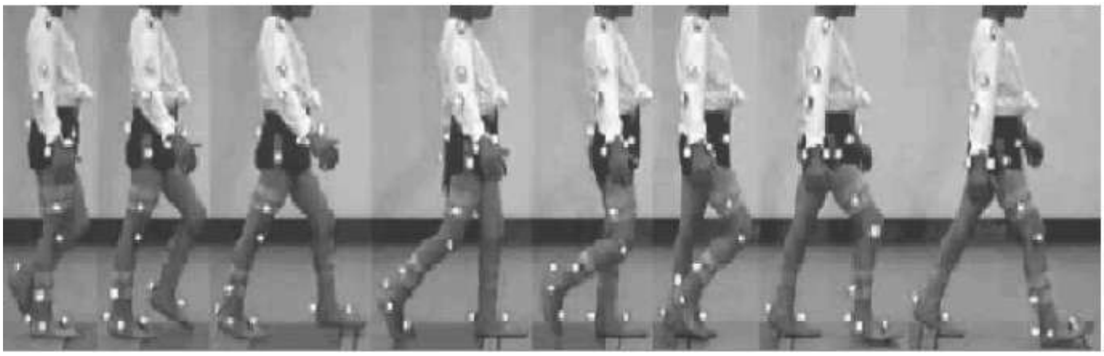

Figure 2 Marker placements for Gait analysis (Representative of Example)

Figure 3 Flexion/extension axis of the KAD (Representative of Example)

Figure 4 Position of the KAD (Knee alignment Device) (Representative of Example)

Figure5 Static Measurement (Representative of Example)

MEASUREMENT PROCEDURE

After taking the subject measurements reflective markers were attached at different locations of the body segment as shown in figure 2.

Pelvic Markers (LASI and RASI) were attached directly over the lowest points of anterior superior iliac spines using double-sided adhesive tape. Sacral Marker (SACR) was attached mid-way between the skin dimples formed by the posterior superior iliac spines. The VCM model is extremely sensitive to errors in location and orientation of the knee-joint axis, and considerable care and practice was needed. The KADs (Knee alignment Device) were attached to both knees with the subject sitting on a plinth high enough from the floor to allow the legs to swing freely. The horizontal wands of the KADs were aligned parallel to the floor. The subject was then asked to actively flex and extend each knee in turn, whilst an observer watched the wand indicating the Flexion/extension axis of the KAD.

The location of the KAD was adjusted until the point was found at which the flexion/extension wand showed minimum movement. The position of the KAD was then marked with a ball pen.

The procedure was repeated for the contralateral knee. The KADs were removed, and the subject asked to stand in the centre of the walkway, whereupon they were reattached; Thigh wand markers (left and right thigh) were aligned with the hip joint centre (greater trochanter) and the flexion/extension axis wand of the KAD with the aid of a full-length mirror, placed at a distance of around 2m lateral to the subject. This arrangement allowed the observer a parallax-free view whilst enabling simultaneous adjustment of the thigh wand. Ankle-joint markers (left and right ankle) were attached directly over the lateral malleoli. Shank wand markers (left and right tibia) were aligned with the ankle-joint markers and the flexion/extension wands, also aided by the mirror. Forefoot markers (left and right toe) were attached to the second metatarsal heads, after asking the subject to flex the toes in order to facilitate identification. Heel markers (left and right Heel) were attached over the os calcis at the same height as the forefoot marker (as determined by a Vernier caliper).

During static measurement the subject was requested to stand quietly on the force platform (centre of walkway) whilst several seconds of video data were recorded.

The KADs were removed, and replaced with a marker-width posteriorly, by a standard marker, and the os calcis marker removed. The half-marker readjustment was found to compensate for soft-tissue movement on standing. Adequate rehearsal was permitted in walking on the walkway to ensure a clean foot strike on the force platform, and encourage a natural gait pattern. Subjects were asked to walk at a self-selected natural velocity barefoot, with gazing forwards in the plane of progression. All the experimental data are presented in results and discussion.

RESULTS AND DISCUSSIONS

Figure 6 shows the left side hip, knee (Flexion/Extension) angles and Ankle (Dorsi/Planterflexion) during the gait cycle for each of the five subjects in the sagittal plane. Similarly the rotation of Hip, Knee and ankle in other plane are also presented in Coronal, Transversal Plane.

Figure 6 shows the arcs of motion at the ankle were found relatively small; yet, they are essential for shock absorption and progression of the body's center of mass. The ankle plantar flexes throughout loading response. Dorsiflexion begins with single support, as the tibia rotates forward over the fixed foot. Rapid plantar flexion begins at terminal double support, with maximum plantar flexor position of 30° attained at toe-off. This action marks the initiation of swing with dorsiflexion throughout the 3 swing-phase segments.

Knee motion were found limited to the sagittal plane. The knee started travel from slight knee flexion at initial contact (5°) to nearly 20° of flexion by the end of loading response. The knee then extended (net flexion) through single support, with peak stance phase extension at 40% Gait Cycle. At the conclusion of terminal stance and preswing, knee flexion was rapid, continuing through initial swing until peak knee flexion (60°) occurred. This trend then was obtained just reversed, with knee extension continuing through terminal swing. Peak knee extension occurred slightly before the end of the swing phase, with minor flexion occurring in preparation for the subsequent stance phase.

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For clinical and research gait analysis it is important to concentrate on the trajectories of knee and ankle joint. Pattern shows the variation of ankle and knee joints in different planes, refer figure 7(a-f). In sagittal plane it is found that the knee is extended at heel strike, moving to 200 of flexion in mid stance and further flexion occurring throughout toe-off. In the coronal plane, adduction of approximately 50 occurs at heel strike and throughout the foot flat phase. During the swing phase the knee abducts and returns to neutral. In the transverse plane the knee internally rotates at heel strike and starts to externally rotate at heel-off until mid-swing when internal rotation starts. In these patterns it is found that the maximum movement of knee and ankle joint in saggital plane only. A prosthetic designer can neglect the motion in others plane.

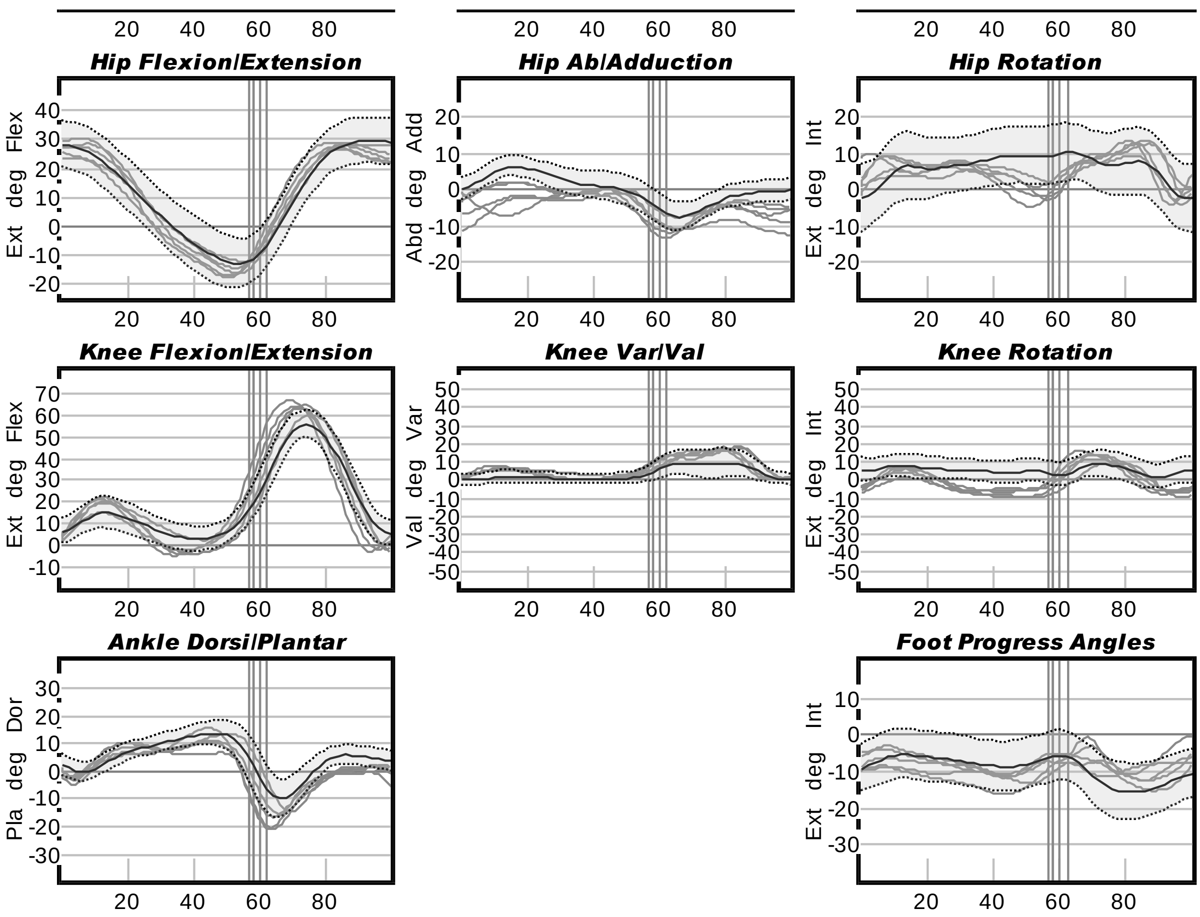

Figure 6 Kinematics for the five subjects during walking cycle in Sagittal, Coronal, Transversal Plane.

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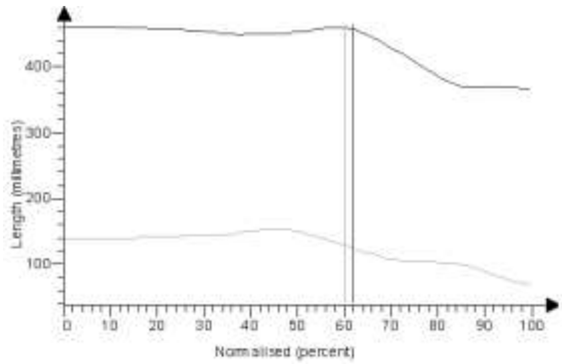
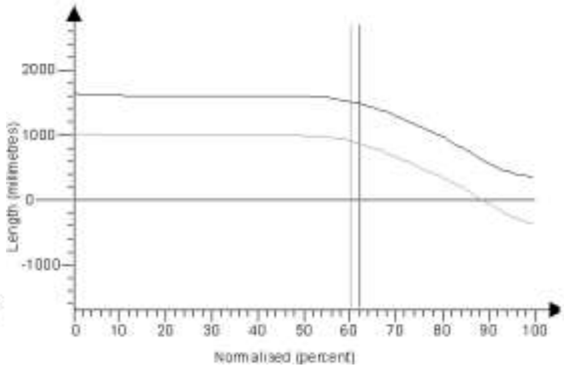
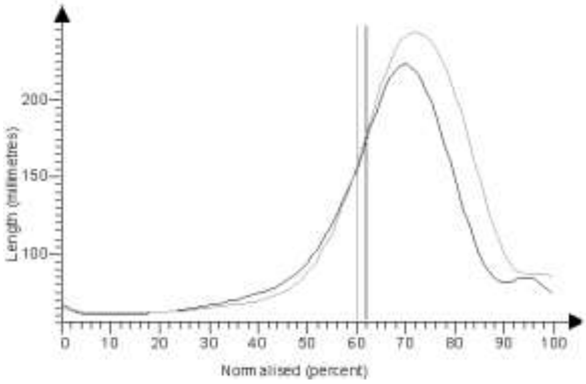


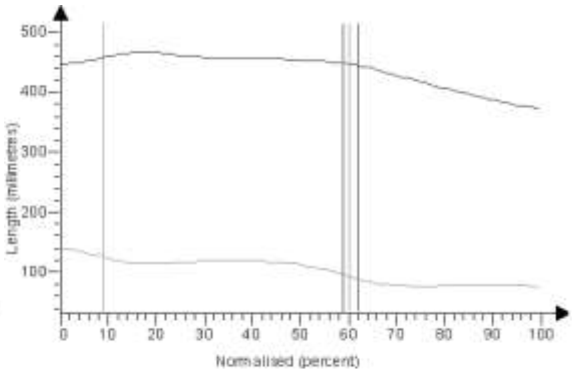
(A) Trajectory of ankle joint in Transverse Plane



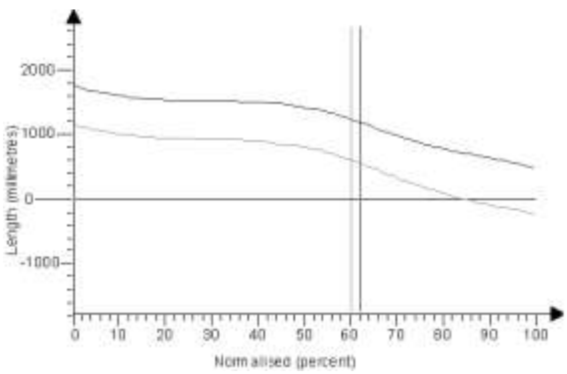
(B) Trajectory of ankle in Frontal Plane



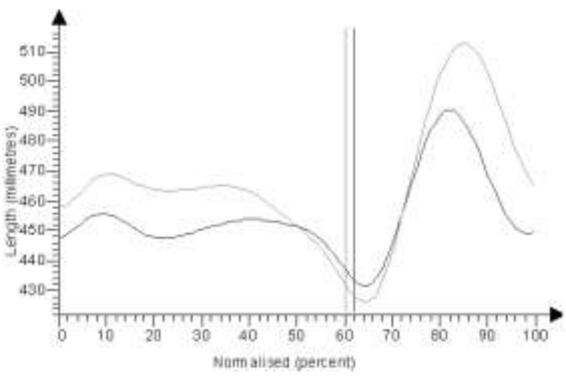
(c) Trajectory of ankle joint in Sagittal Plane



(d) Trajectory of Knee joint in Transverse Plane



(e) Trajectory of Knee joint in Frontal Plane



(f) Trajectory of Knee joint in Saggital Plane

Figure 7. Trajectories of Knee and ankle joint in various planes

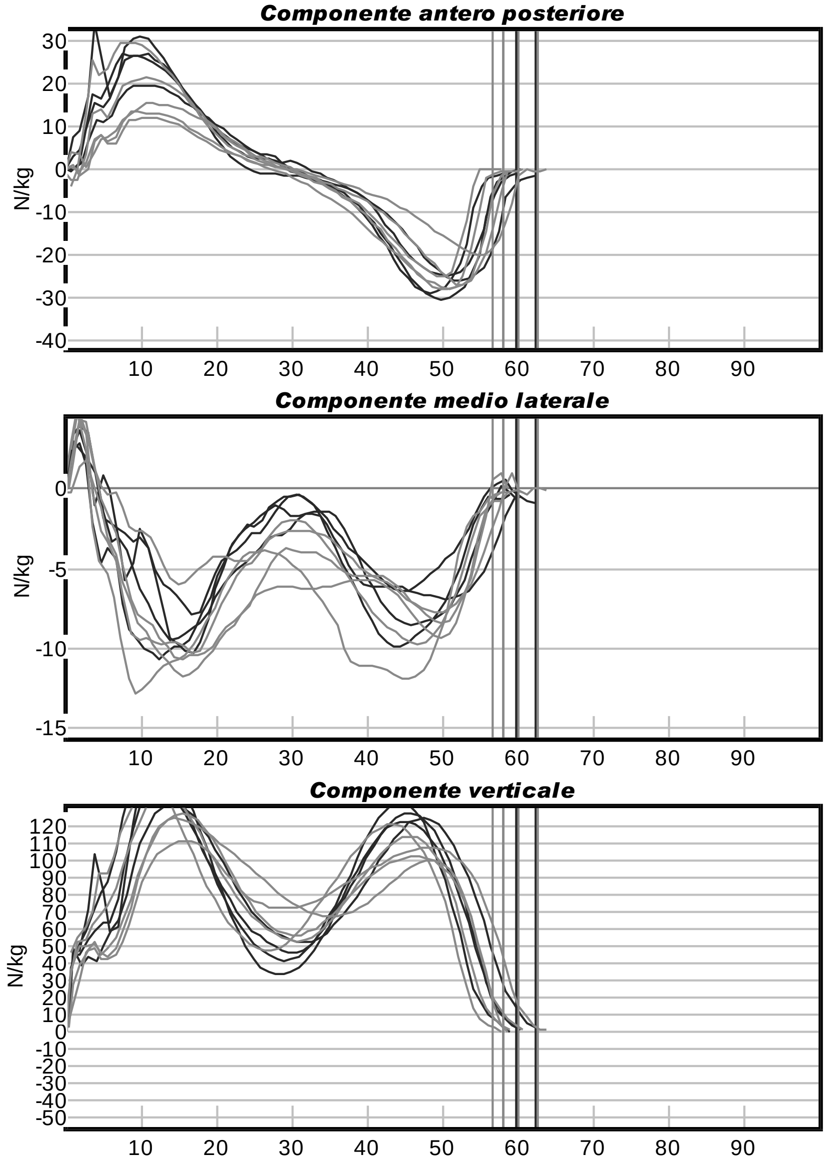


Figure 7 Normal vertical forces increase in weight acceptance shortly after heel contact, decrease through midstance and increase again at pushoff.

Ground Reaction Measurement

Force platform embedded in a walkway provide information about the center of pressure or point of application of the GRF vector. The ground reaction force is equal in magnitude and opposite in direction to the force that the body exerts on the supporting surface through the foot. The ground reaction force vector (GRFV) passes upward from the foot and produces movement at each lower extremity joint. We can visualize the GRFV by studying laboratory investigations of normal gait that employ force plates to measure the GRFV's three-dimensional orientation. The GRFV differs from a "gravity line," which is a vector that extends vertically from the center of gravity of a static body. Instead, the GRFV is a "reflection of the total mass-times-acceleration product of all body segments and therefore represents the total of all net muscle and gravitational forces acting at each instant of time over the stance period" [12]. The ground

reaction force is not the only force acting on joints during gait. The weight and inertia of a moving segment has an effect on the segments distal and proximal to it [13]. Moving the upper leg influences movement in the lower leg. These joint reaction forces can be important. However, joint reaction forces are relatively small in the lower extremity, at least during stance phase.

Therefore, clinicians or biomechanical engineers can use the GRFV's position by itself to understand the forces that human muscles must control during gait's stance phase as presented in figure 7. Normal vertical forces increase in weight acceptance at heel contact, decrease through midstance and increase again to the same magnitude at pushoff.

CONCLUSIONS

The normal human locomotion has been investigated from kinematic and kinetic point of view through gait analysis in this paper. The experimental data not only provide input but also validate any mathematical model of leg mechanism. It may be noticed that the maximum displacement of ankle and knee joint is measured in sagittal plane. Therefore a prosthetic designer may neglect the displacement of the ankle and knee joint in other two planes. The design of knee or ankle joint mechanism will depend upon the trajectories measured in sagittal plane. The end result of the clinical gait assessment procedure for the orthotist is the determination of the orthotic design and recommendation. Orthotic design takes the form of three-point force systems specific to the joint angulations alignments, the planes of deviation and the necessary support due to motor deficits.

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